DEPARTMENT OF COMMERCE AND LABOR

BUREAU OF STANDARDS

S. W. STRATTON, Director

ON THE DETERMINATION OF THE MEAN HORIZONTAL INTENSITY OF INCANDESCENT LAMPS

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EDWARD P. HYDE, Associate Physicist

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Bureau of Standards

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ON THE DETERMINATION OF THE MEAN HORIZONTAL INTENSITY OF INCANDESCENT LAMPS.

By Edward P. Hyde and F. E. Cady.

INTRODUCTION.

In a paper "On the Determination of the Mean Horizontal Intensity of Incandescent Lamps by the Rotating Lamp Method," published several months ago in abstract in the Electrical World,[1] and subsequently in full in this Bulletin,[2] the authors, after reviewing briefly the various methods employed in the determination of mean horizontal intensity, described an investigation, undertaken at the Bureau of Standards, of the possible errors of the rotating lamp method. This method is the one in almost universal use in the United States. Recently another paper[3] on the same subject has been published by Uppenborn in Munich. Inasmuch as the results given in the latter paper are at variance with those obtained at the Bureau of Standards, and have, moreover, been quoted in the United States as discrediting the determination of mean horizontal intensity by the convenient method of rotating the lamp about its axis of figure, it seemed desirable to present some further data obtained at the Bureau, and also to call attention to several points of difference in the two methods employed to study the accuracy of the rotating lamp method.

According to the results obtained previously at the Bureau in the study of this method, two possible sources of error were found when the lamp was rotated, one due to a distortion of the filament produced by centrifugal forces, and one due to the flickering nature of

[1] Electrical World, Nov. 17, 1906; p. 956.
[2] This Bulletin, 2, p. 415.
[3] Electrotechnische Zeitschrift, Feb. 14 and 21, 1907; pp. 139, 168.

the illumination of the photometer screen, produced primarily by the nonuniformity of the horizontal distribution curve of the lamp. Of these two effects the first was found to be quite small at moderate speeds of rotation for all types of filaments examined, the maximum error at 500 or 600 revolutions per minute being only about 1 per cent.

The error due to flicker, however, was found to be quite large for lamps of certain types in which the horizontal distribution curves deviate greatly from a circle. Moreover, the error was found to be largely a function of the individual, some observers reading a flickering light too high and others too low. Except, however, for a few types of lamps (of the number examined) in which the flicker is very annoying, the combined error due to both bending and flicker is probably not much over 1 per cent, particularly if the speed of rotation is increased to 300 or 400 r. p. m. By the use of a single auxiliary mirror as described in the original paper, the flicker pertaining to all types of filaments is greatly reduced, so that even those lamps with the most irregular horizontal distribution curves can be photometered with accuracy at a speed of only 200 or 300 r. p. m., at which the effect of bending is negligible for all types of lamps studied.

In the investigation at the Bureau a substitution method was employed, which did not necessitate a determination of the actual candlepower of the lamps studied. Any change in candlepower, due either to the bending of the filament or to the flicker could be detected and measured separately. For the nine different types of lamps investigated, as described and illustrated in the detailed paper referred to above, the greatest change in mean horizontal candlepower due to bending at a speed of 550 r. p. m. was found to be only about 1 per cent. For most of the types of filaments the effect of bending was to decrease the mean horizontal intensity, but for one type the effect was to increase it by about 1 per cent.

In Uppenborn's investigation the lamps were measured for actual mean horizontal candlepower, by taking the mean of 36 readings made every 10° in the horizontal plane. The values obtained in this way were taken as the true values, and a comparison of the candlepower values obtained by other methods with these standard values gave the errors incident to the several methods studied.

In this way 8 lamps of different sizes, types, and voltages were measured for mean horizontal candlepower, first by the point-to-point method, and subsequently by the rotating lamp method. A comparison of the results indicated that the values obtained by the rotating lamp method were uniformly too low, the amount of the error ranging from 3.3 to 9.9 per cent. Uppenborn attributes the errors to the distortion of the filament on rotation; but since the experiments at the Bureau had shown in no case an error much over 1 per cent due to this cause, it seemed desirable to make some further experiments by a different method, and using lamps of other types than those previously investigated. The differences in the results obtained at the two laboratories could not have been due to differences in speed used, for in the experiments at the Bureau various speeds were employed up to 550 or 600 r. p. m., whereas in Uppenborn's work, although no definite statement is made of the speed at which the results quoted above were obtained, it is very probable that no greater speed than 450 or 500 r. p. m. was employed, since this is the limiting speed stated in another part of the paper.

METHOD AND RESULTS OF RECENT EXPERIMENTS.

Before conducting experiments upon types of filaments differing from those investigated previously a few measurements were made on some of the same types of filaments, in order to check the results obtained by the former method using the rotating mirrors, with those obtained by the new method. In this new method the lamp was placed in a universal lamp-holder which could be set at different angles, but which also could be rotated. In general, readings were made first with the lamp spinning, then at every 10° in the horizontal plane with the lamp at rest, and again with the lamp spinning. The speed was then gradually increased, in some experiments until the filament touched the bulb. This way of comparing the point-to-point method with the rotating lamp method was chosen as being somewhat similar to that employed by Uppenborn, with the advantage that being a substitution method it does not involve the actual calibration of the comparison lamp such as is done in Uppenborn's experiments.

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The first lamp studied was a 110-volt 16-cp oval anchored filament lamp (Fig. 1, No. 1). In expressing the results of this, as of subsequent experiments, since only relative values are desired, the convenient method will be used of adopting an arbitrary unit such that the intensity under some one condition will be taken as unity, and then all the other values will be expressed in terms of this unit. In this way the percentage changes will be evident immediately.

The lamp was first rotated at about 420 r. p. m. and readings were taken. Then measurements were made every 10° in the horizontal plane with the lamp stationary, and finally the lamp was rotated again at 420 r. p. m. If we call the first rotating value 1.000, then the value of mean horizontal intensity obtained by the point-to-point method is 1.002, and the value found on subsequent rotation 0.999. In other words, the results obtained by the two methods, the speed of rotation being 420 r. p. m., agree to within 0.2 or 0.3 per cent, which is within the range of experimental error.

Since in this type of lamp the filament is well supported, one would not expect as large errors as for some other types, such as the double filament lamp (Fig. 1, No. 2). In this type of lamp, which was next studied, the filament consists of two long, slender loops, entirely unsupported except at the leading-in wires. Denoting by 1.000 the value of mean horizontal candlepower obtained at the beginning at a speed of 350 r. p. m., the value found by the point-to-point method every 10° is 1.005, and the value obtained at the end at a speed of 350 r. p. m. is 0.999. This decrease of 0.5 per cent at a speed of 350 r. p. m. is in very good agreement with that obtained in the previous investigation using the rotating mirror method. The mean of a number of determinations using this method indicated a decrease of 0.9 per cent at a speed of 500 or 600 r. p. m.

Another lamp of the double filament type gave the following results: Mean horizontal intensity at 180 r. p. m., 1.000 at the beginning of the set of measurements, 1.003 in the middle of the set, and 0.998 at the end; by the point-to-point method 1.002, or an average decrease of 0.2 per cent, which also agrees with the values previously obtained for this type of lamp.

Having shown now that the error at a speed of 180 r. p. m. for this type of filament is negligibly small, the two lamps were mounted successively in the rotator and the speed was increased until the

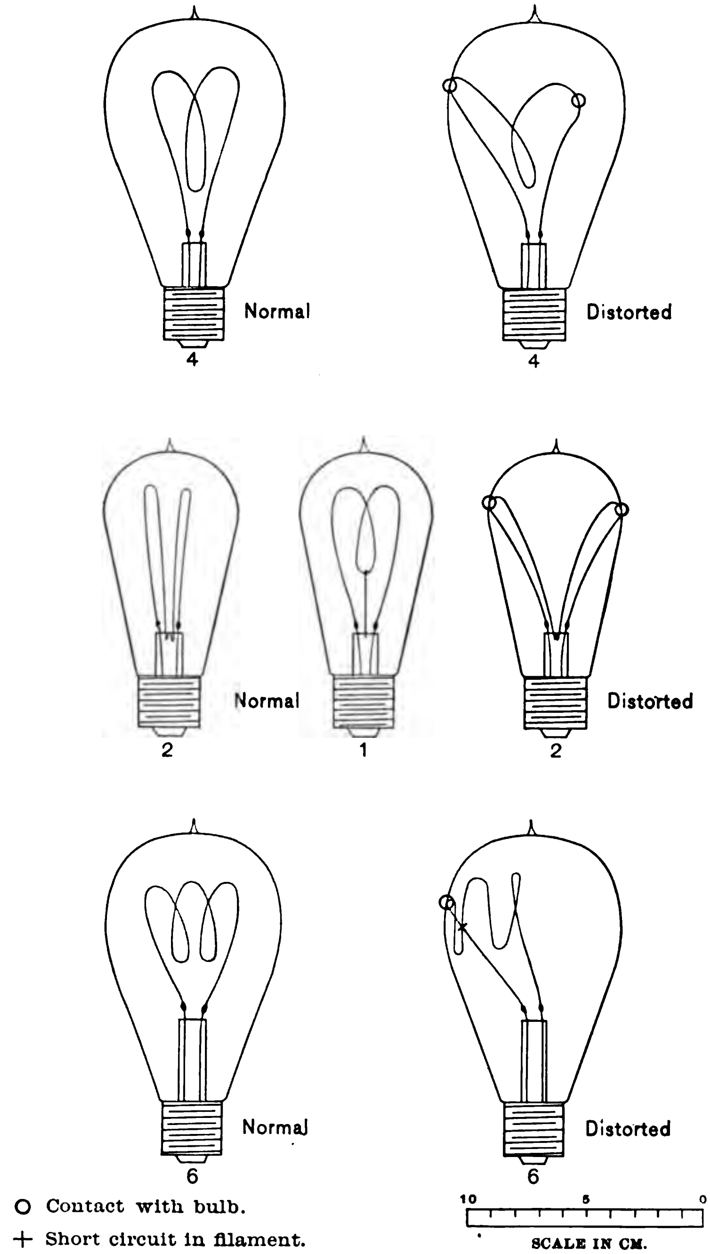
Normal
4
Distorted
4
Normal
2
1
Distorted
2
Normal
6
Distorted
6
O Contact with bulb.
+ Short circuit in filament.
10
5
0
SCALE IN CM.

Fig. 1.

TABLE I.

Values of Mean Horizontal Intensity of Double Filament Lamps at Different Speeds of Rotation.

LAMP NO. 2.

Speed	Relative intensity	Current	Remarks
180 r. p. m.	1.000	0.5232	
400 r. p. m.	0.990	0.5232_5	
750 r. p. m.	0.951	0.5237_5	Both loops touching bulb.
180 r. p. m.	0.997	0.5231	Loops shaken loose. Filament has a "set."
400 r. p. m.	0.988	0.5231	
470 r. p. m.	0.986	0.5231	
200 r. p. m.	0.999	0.5231	
			(Speed gradually increased with following results:)
	0.985		Just before either loop touched bulb.
	0.978	0.5232	One loop touching bulb.
	0.966	0.5232_5	Both loops touching bulb.
			(Lamp stopped, loops shaken loose from bulb, and cycle repeated.)
	0.986	0.5231_5	Just before either loop touched bulb.
	0.981	0.5231_5	One loop touching bulb.
	0.949	0.5233_5	Both loops touching bulb.
	0.995	0.5231	Both loops shaken loose.

LAMP NO. 3.

Speed	Relative intensity	Current	Remarks
200 r. p. m.	1.000	0.5217	
510 r. p. m.	0.985	0.5216_5	
725 r. p. m.	0.964	0.5217_5	One loop touching bulb.
180 r. p. m.	0.995	0.5216_5	Lamp stopped and loop shaken loose.
330 r. p. m.	0.989	0.5216_5	
500 r. p. m.	0.989	0.5216	
750 r. p. m.	0.966	0.5216	One loop touching bulb.
820 r. p. m.	0.959		Second loop spreading. Possibly touched bulb.
180 r. p. m.	0.997	0.5216_5	Lamp stopped and loop shaken loose.
400 r. p. m.	0.992		
180 r. p. m.	0.997		
500 r. p. m.	0.991		
775 r. p. m.	0.971		One loop touching bulb.

filaments touched the bulb, in order to see how large a decrease in mean horizontal intensity could be obtained with this type of lamp, and what the speed must be in order to accomplish this maximum reduction. The results are given in Table I. In the first column are given the different speeds used, in the second column the values of mean horizontal intensity in terms of an arbitrary unit, in the third column the currents under the different conditions, and in the fourth column brief explanatory notes. Usually when the filament was forced against the bulb it sealed itself to the glass (Fig. 1, No. 2, distorted) and had to be shaken loose after stopping the lamp.

An inspection of the table shows that the maximum decrease in mean horizontal intensity obtained under any condition was about 5 per cent, when at a speed of 750 or 800 r. p. m., the two loops of the filament were each separately touching the bulb, one at one side and one at the other. In no case did the decrease amount to more than 1.5 per cent so long as the filament did not touch the bulb. In order to test this point directly, the two series of readings recorded near the end of the table for lamp No. 2 were made. One observer made the electrical measurements, a second observer read the photometer, and a third observer increased the speed gradually and noticed when the filament touched the bulb. It is seen that as each loop touched, a decrease in candlepower resulted, but it was impossible to say à priori how much the intensity would decrease when the filament touched.

These various results are not surprising when we consider the effect of a contact of the filament with the bulb. On touching the bulb the filament is cooled, and so a decrease in candlepower is to be expected. Moreover the amount of the cooling, and consequently the decrease in candlepower, depends upon whether the filament touches in only one point, or whether it lies against the glass for an appreciable part of its length, so that the decrease in candlepower is not always the same when a filament touches the bulb.

Independent evidence of the cooling of the filament and the consequent decrease in candlepower is afforded by a study of the current values. Although a change in voltage of from 100 to 110 volts produced an increase in resistance of only 2 parts in 1000, yet the cooling due to the contact of a small part of the filament with the bulb was sufficient to increase the current appreciably, in one case

the change amounting to 1 part in 1000. But although the resistance changes are indicative of the cooling, quantitative relations could not be deduced because of the very complicated nature of the phenomenon.

It would seem that the double filament lamp would probably show a greater decrease in mean horizontal candlepower due to bending than any other type of lamp made in the United States. The two loops of which the filament is composed are long and slender, and being unsupported are susceptible to centrifugal forces. Moreover the candlepower in the direction of the tip is very small and consequently the decrease in the effective length of the sides of the loop on rotation is not compensated to any extent by the tip. A lamp having a relatively large tip candlepower would not be expected to show as much decrease in mean horizontal candlepower due to bending as a lamp with a small tip candlepower. But although the double filament lamp seemed to the writers to represent one of the worst cases for high-speed rotation, since the large errors found by Uppenborn were obtained with filaments having a turn in them somewhat similar to the common oval anchored filament, it was thought desirable to make some tests with lamps of this type.

The maximum error which Uppenborn obtained, -9.3 per cent, was found for a 32-cp 110-volt 1½-turn oval filament with no anchor. Since the writers do not know of any type of lamp made in the United States corresponding exactly with that described by Uppenborn, they obtained through the courtesy of the Franklin Electric Manufacturing Company two special lamps (Fig. 1, No. 4), which were identical in every respect with the regular 32-cp 110-volt, oval anchored lamp except that the anchor wire was omitted, in order that the filament might be left as unstable as possible. The dimensions of the filament agreed approximately with those given by Uppenborn, the total height of the filament used at the Bureau being about 75 mm instead of 65 mm, and the vertical axis of the oval being 50 mm instead of 40 mm.

These two lamps were studied in the same way as the double filament lamps described above, except that the readings by the point-to-point method were made every 15° instead of every 10° as in the preceding determinations. Lamp No. 4 was first measured

at different speeds up to 600 r. p. m., the greatest change in mean horizontal candlepower, as compared with the value determined by the point-to-point method, being only 1 per cent. In these determinations the filament did not touch the bulb, although it approached close to it. Subsequently the lamp was kept at a speed of 600 r. p. m. for some minutes, and though at first the filament was separate from the bulb it gradually spread and ultimately came into contact with the glass. Just before the filament reached the bulb the mean horizontal intensity was about 1 or 1.5 per cent low; but after coming into contact the intensity decreased to a value 3 or 4 per cent lower than that determined by the point-to-point method. The current also underwent a very appreciable change when the filament touched the bulb.

The speed was now increased to 800 r. p. m., at which both loops were in contact with the glass (Fig. 1, No. 4, distorted). The mean horizontal intensity was found to be about 7 per cent low, and the current to have undergone another change in the same direction as before. While rotating at the high speed of 800 r. p. m. a star crack developed and the filament burned out so that it is possible that a part of the observed 7 per cent change in candlepower may have been due to the constantly deteriorating vacuum.

The other special 110-volt 32-cp lamp (No. 5) showed approximately the same characteristics as lamp No. 4, except that the filament touched the bulb first in one point and then in a second point, the mean horizontal intensity decreasing to about 97 per cent of its original value as determined by the point-to-point method. The current also showed a marked change due to the cooling of the filament.

In addition to the two special 32-cp 110-volt lamps, the Franklin Electric Manufacturing Company furnished also two special 32-cp 220-volt lamps without anchors. The filaments were of the 2½-turn type such as are usually provided with two anchors (Fig. 1, No. 6). Without the anchors the filaments are quite unstable and entirely unsuited for high-speed rotation. Consequently they were forced against the bulb at the comparatively low speed of 400 or 500 r. p. m. Before touching the bulb the decrease in candlepower was not more than 1 per cent for either lamp, and, in fact, the error due to the flicker, which is somewhat annoying for this type of

lamp at the low speed of 200 r. p. m., was of the same order of magnitude as that due to bending. It is interesting to note in this connection that the same kind of error due to flicker was observed in these experiments as that described in the former paper. Thus while one observer obtained for the flickering light a value higher than that obtained by the point-to-point method, the other observer obtained a value lower than the true value. Moreover the two observers deviated from the true values in the same way as they did previously in the original investigation. This point will be mentioned again later. It is sufficient to note here that at the higher speeds this error due to flicker disappeared and the different observers obtained approximately the same errors due to bending.

At speeds of 600 or 700 r. p. m., when the filaments were well over against the glass, the decrease in candlepower reached a value as high as 4 per cent for one of the lamps; but whenever the change in candlepower was large there was always a very appreciable change in resistance, indicating that the change in candlepower was due probably, to a large extent, to a cooling of parts of the filament. In Fig. 1, lamp No. 6 is shown both when new and after having touched the bulb and burned out. At the high speed of 675 r. p. m. one loop was short-circuited by the next and the filament burned out at the point of contact.

From a consideration of all the data given in the preceding paragraphs it is seen that the maximum error observed, due to a bending of the filament, was not in any case greater than 1.5 per cent, provided the filament did not touch the bulb, even though the filament was bent so as almost to touch the bulb. The speed of rotation necessary to force the filament against the bulb was not less than 600 r. p. m. except for the special 32-cp 220-volt lamps without anchors, and for these it was about 400–450 r. p. m. For most common types of lamps the speed would be much higher than 600 r. p. m., and it is probable that for some types a rupture of the filament would occur before the filament would touch the bulb.

When the filament touches the bulb changes in candlepower of as much as 6 or 7 per cent may take place, but as these large changes are always accompanied by relatively large changes in resistance, it is probable that they are due to a cooling of the filament owing to the contact with the glass.